

Nondestructive Evaluation for Moon and Mars Exploration

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NASA Langley Research Center

ASNT Research Symposium, 2022



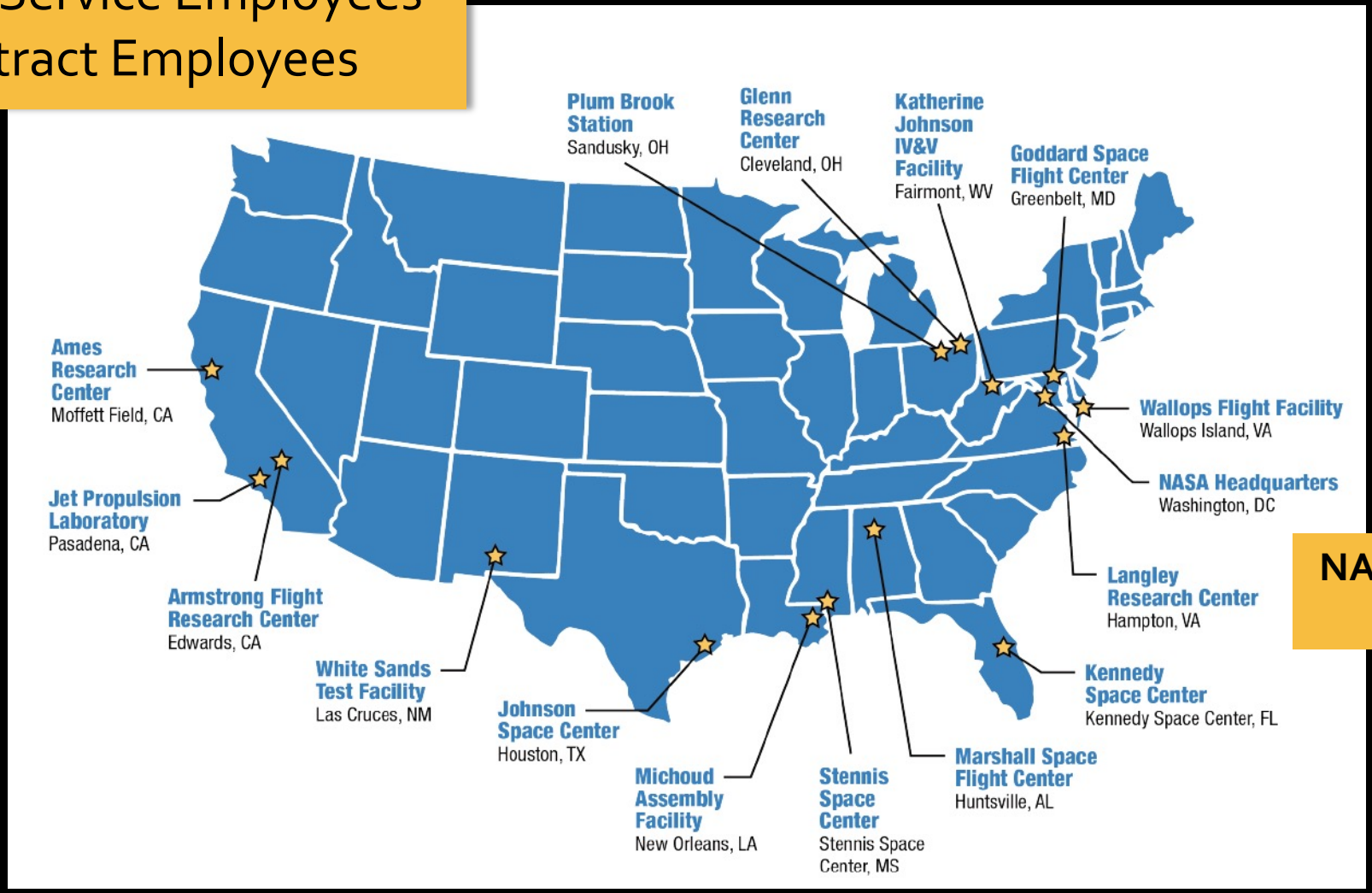
WHY THE MOON

Agenda

- Nondestructive evaluation (NDE) at NASA Langley
- NDE for Moon and Mars
  - Getting there
  - On-surface activities
- Uncrewed space exploration

National Aeronautics & Space Administration

14 Major Centers/Facilities
~17,000 Civil Service Employees
~40,000 Contract Employees



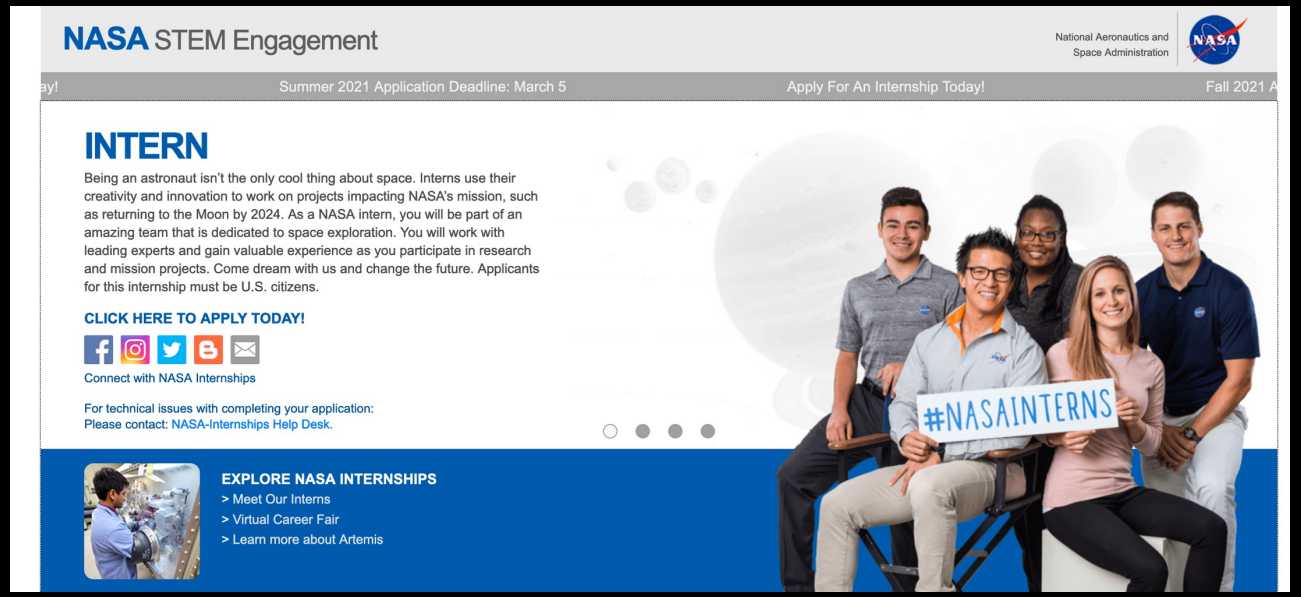
NASA Langley is the oldest center, 105 years!

NASA Internships, Fellowships:

https://intern.nasa.gov/

NASA Jobs:

https://www.usajobs.gov/







NASA Langley Research Center
National Resource for Aerospace R&D
Since 1917

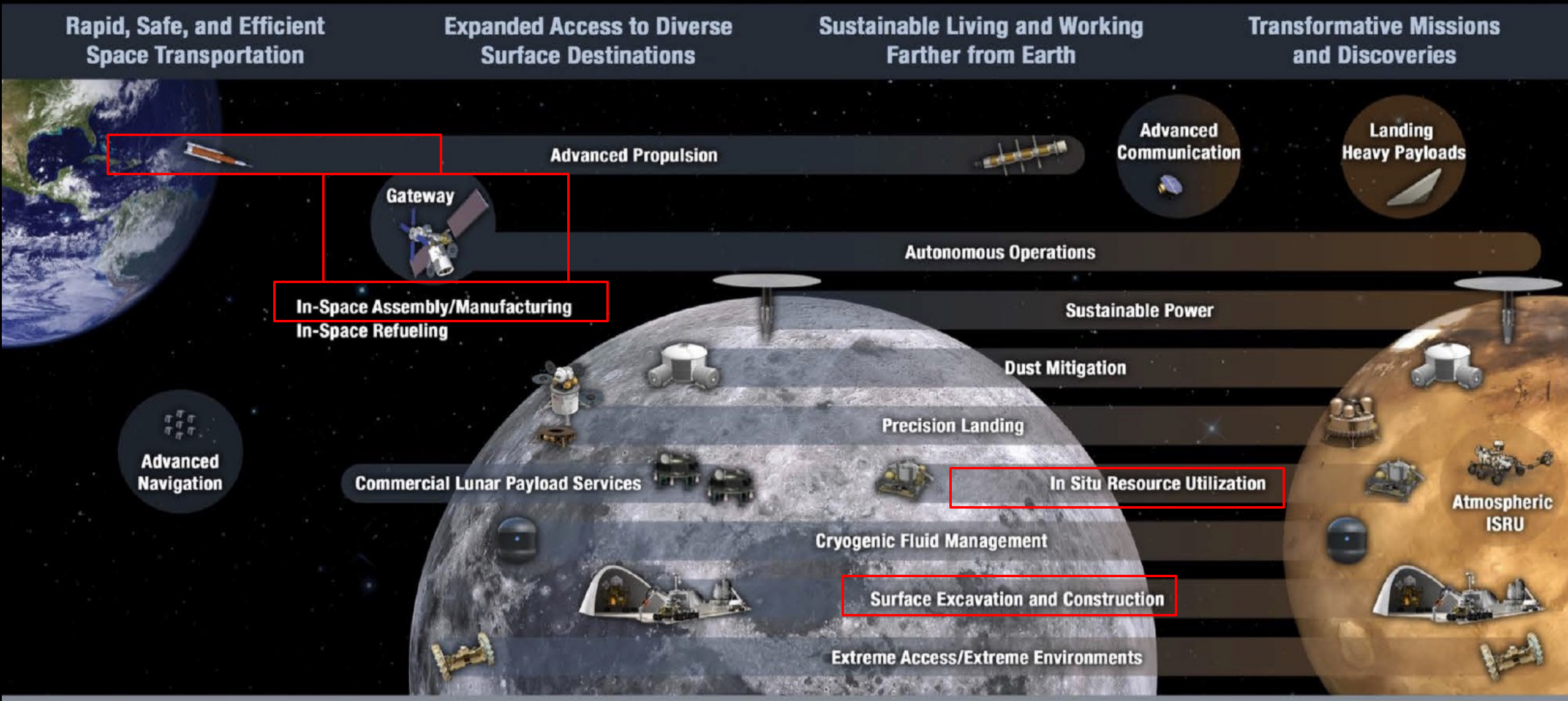
Nondestructive Evaluation Sciences Branch

- Primary Role: Serve as the research NDE branch at NASA
- Work across spaceflight exploration, aeronautics, space technology
- 24 Personnel
  - Researchers, technicians, support staff
  - Physicist, Engineers, Mathematician



- **Advanced NDE Solutions**
  Development of unique solutions using state-of-the-art NDE technologies such as Eddy Current, Ultrasound, Thermography and X-ray CT
- **Emerging NDE Technologies**
  Development of unique NDE technologies such as Terahertz, wavefield imaging, nonlinear ultrasound, Raman spectroscopy
- **Physics-Based Modeling**
  Development of both computational and analytic models
- **Advanced Data Analysis and Interpretation**
  Development of advanced analytic methods to interpret large complex data sets and machine learning algorithms
- **SHM Sensor Implementation and Interrogation**
  Development of advanced methods of applying and interrogating sensors for structural health monitoring

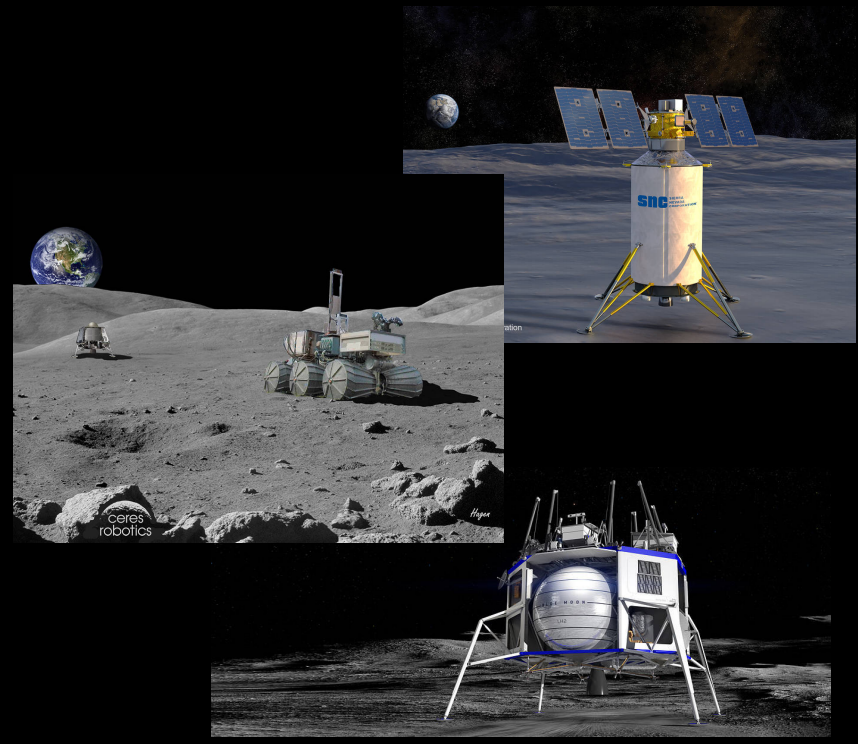
Reaching The Moon And Mars Faster With NASA Technology



2020 GO | LAND | LIVE | EXPLORE 203X

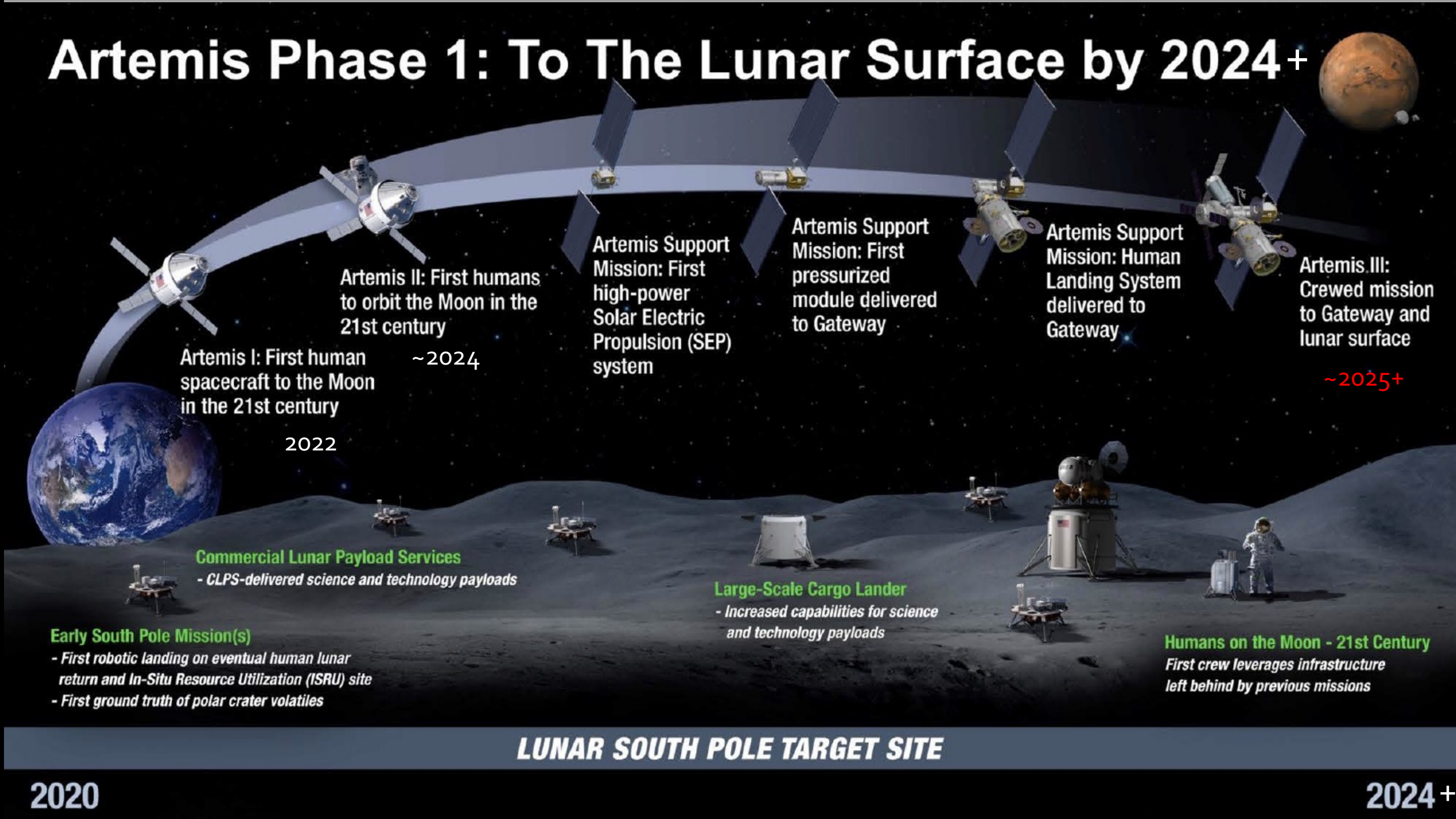
Moon and Mars

- U.S companies delivering scientific instruments and technology demonstrations to lunar surface
- Gateway, in orbit around the Moon, will support human and scientific missions
- Human landers take astronauts to the surface of the Moon
- Space Launch System rocket and Orion spacecraft to build the Gateway and transport astronauts to and from Earth.

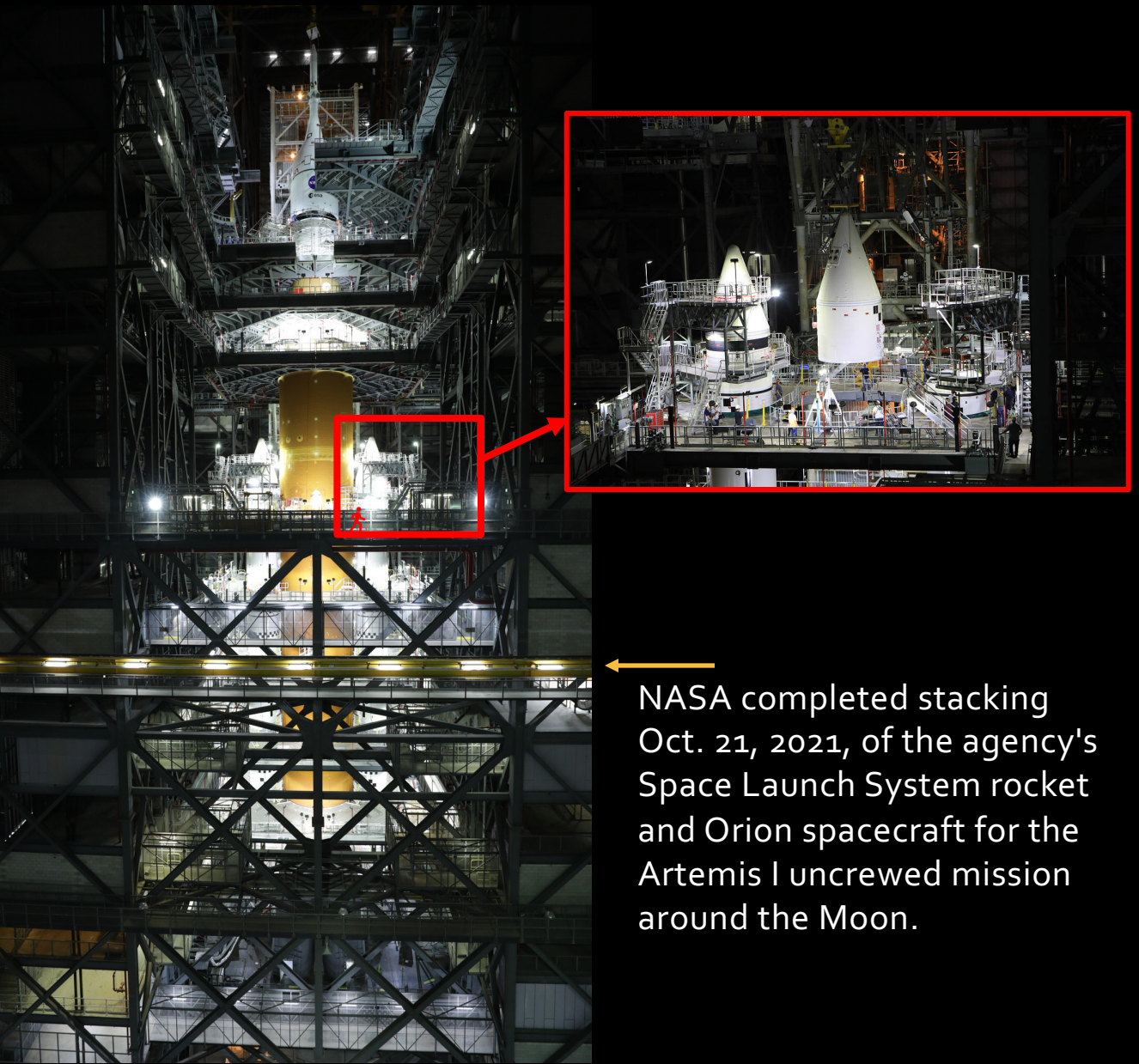


Examples of concept landers from Blue Origin, Ceres robotics, Sierra Nevada Corp. (others can be found at: https://www.nasa.gov/press-release/nasa-announces-new-partnerships-for-commercial-lunar-payload-delivery-services

Artemis Phase 1: To The Lunar Surface by 2024+



Getting There: Orion & Space Launch System



NASA completed stacking Oct. 21, 2021, of the agency's Space Launch System rocket and Orion spacecraft for the Artemis I uncrewed mission around the Moon.

NASA's Space Launch System (SLS) rocket with the Orion spacecraft aboard atop a mobile launcher at Launch Complex 39B.

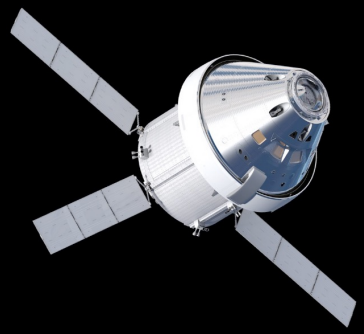


NDE for Orion and SLS

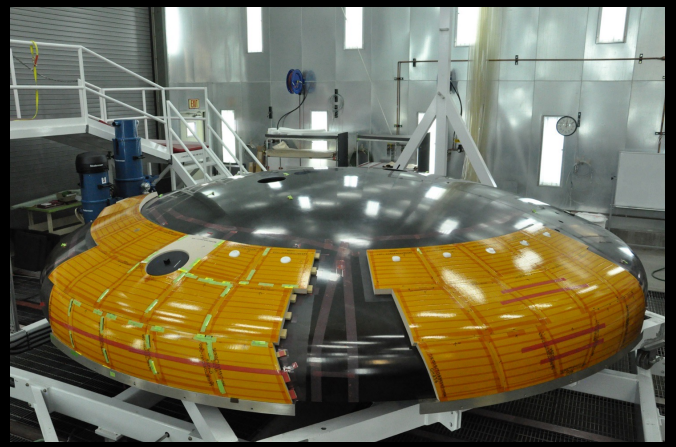
Orion – Thermal Protection System

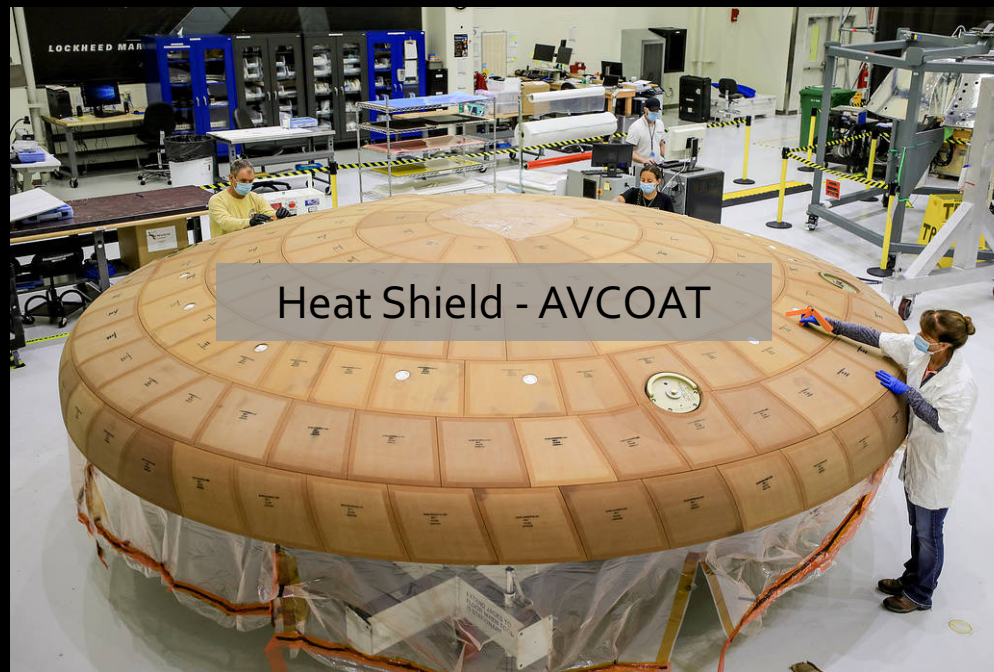
Artemis I - Orion module, Oct. 2021



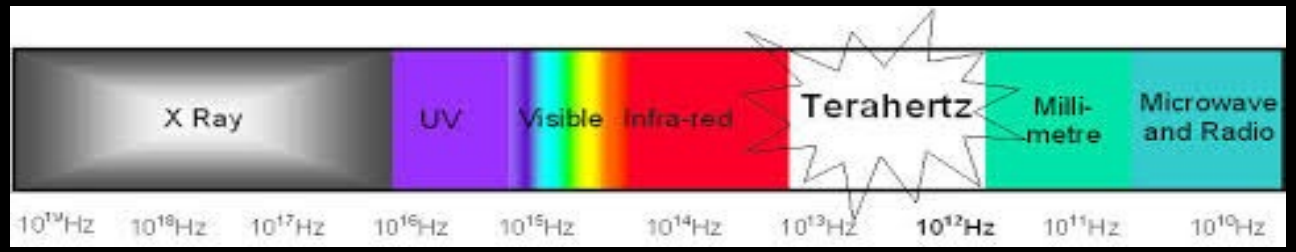








Orion: Terahertz Imaging



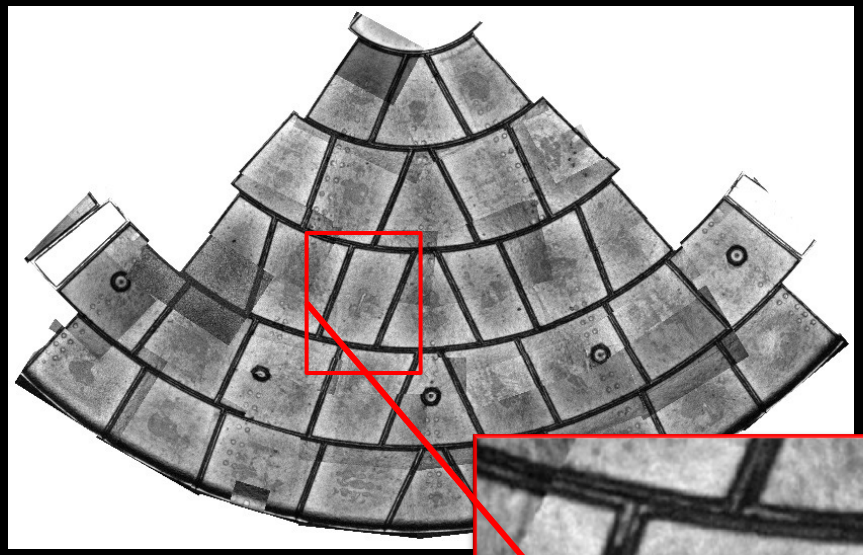


Terahertz Inspection of the Manufacturing Demonstrator Unit at the Fabrication Facility

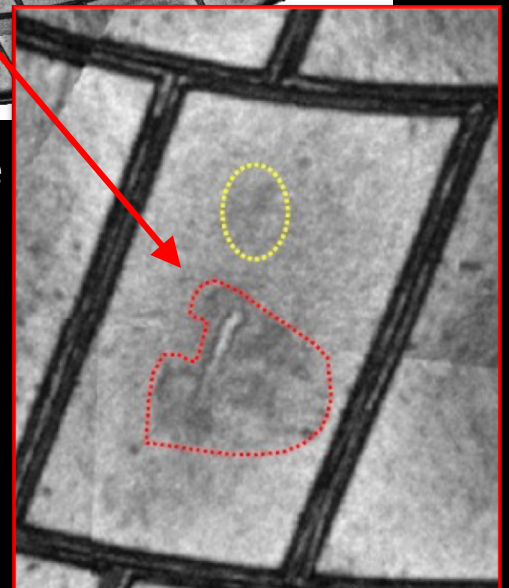


<u>Avcoat – Ablative heat shield</u>
Very low thermal conductivity
Very low electrical conductivity
Highly attenuates Ultrasound
Requires single-sided inspection

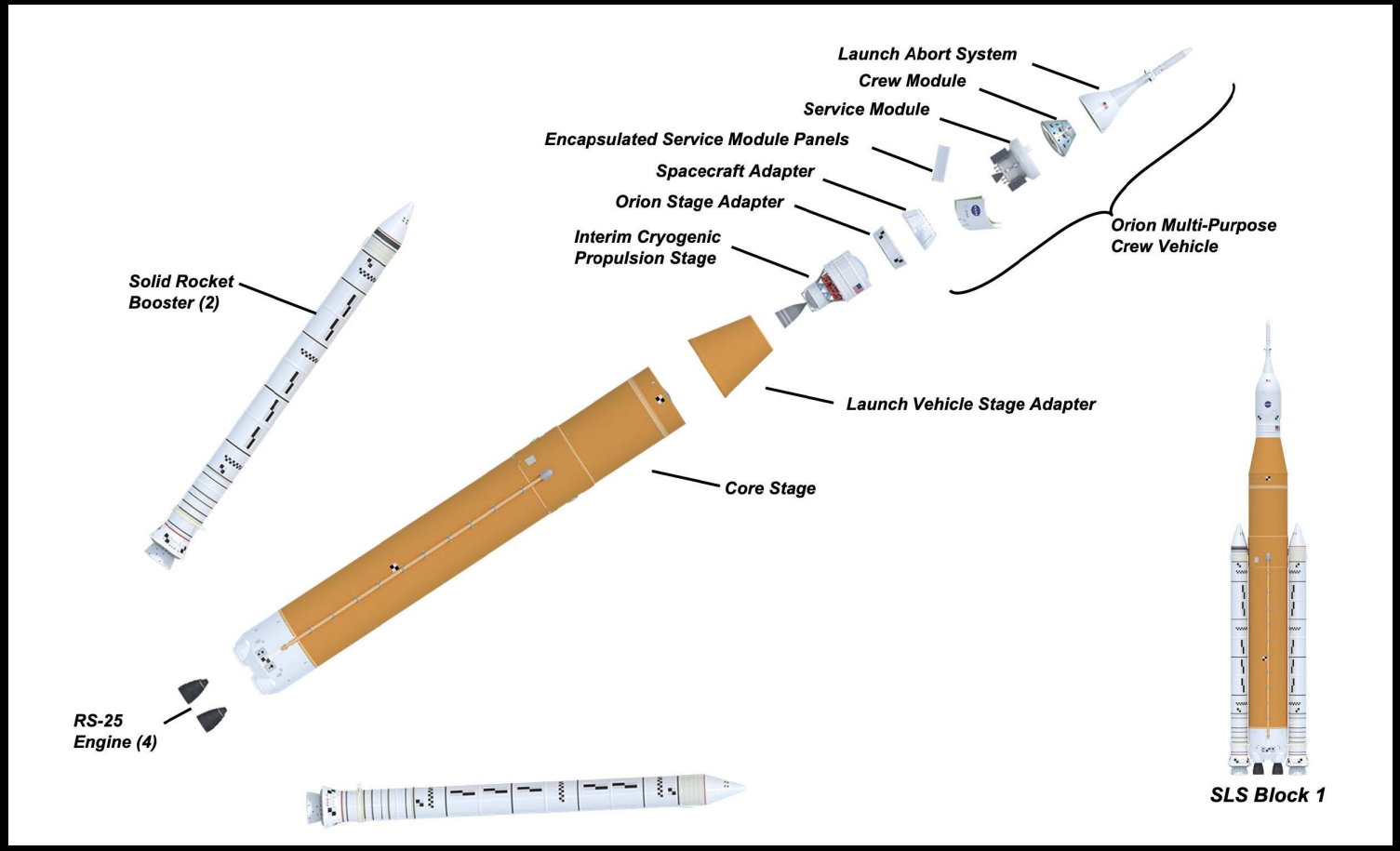
Mosaic Terahertz Scanned Image



Porosity at the bond-line



Space Launch System





Artemis Block 1 integrated SLS and Orion:
322’ tall, 5.75 million pounds, will produce 8.8 million pounds thrust
(15 percent more than Saturn V)

Artemis 1 - SLS Core Stage

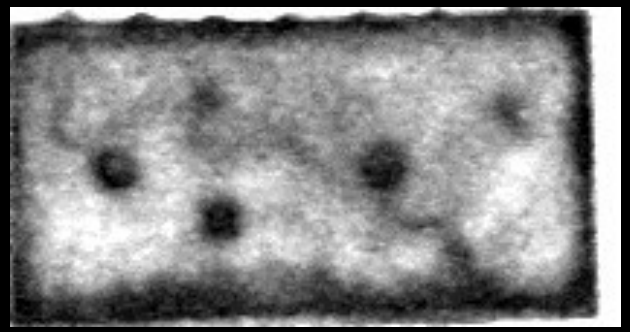
- Inspection for voids in the RT455 ablator materials in the aft end of the rocket.



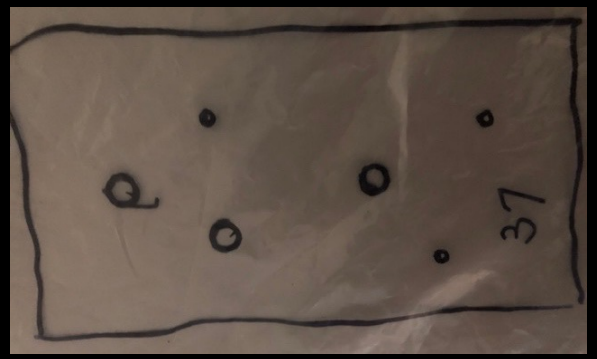
Examples of inspection samples containing voids:

- *RT-455* is a mix of resin and cork material
- ½” voids were easily detected, ¼” voids 80% detected

Terahertz image
“C-Scan” format:



Flaw pattern:





Void layer is at ~1/4” thickness,
close to the aluminum plate mounting

Full sample thickness ~3.125”

POC: Eric Burke and Eric Madaras





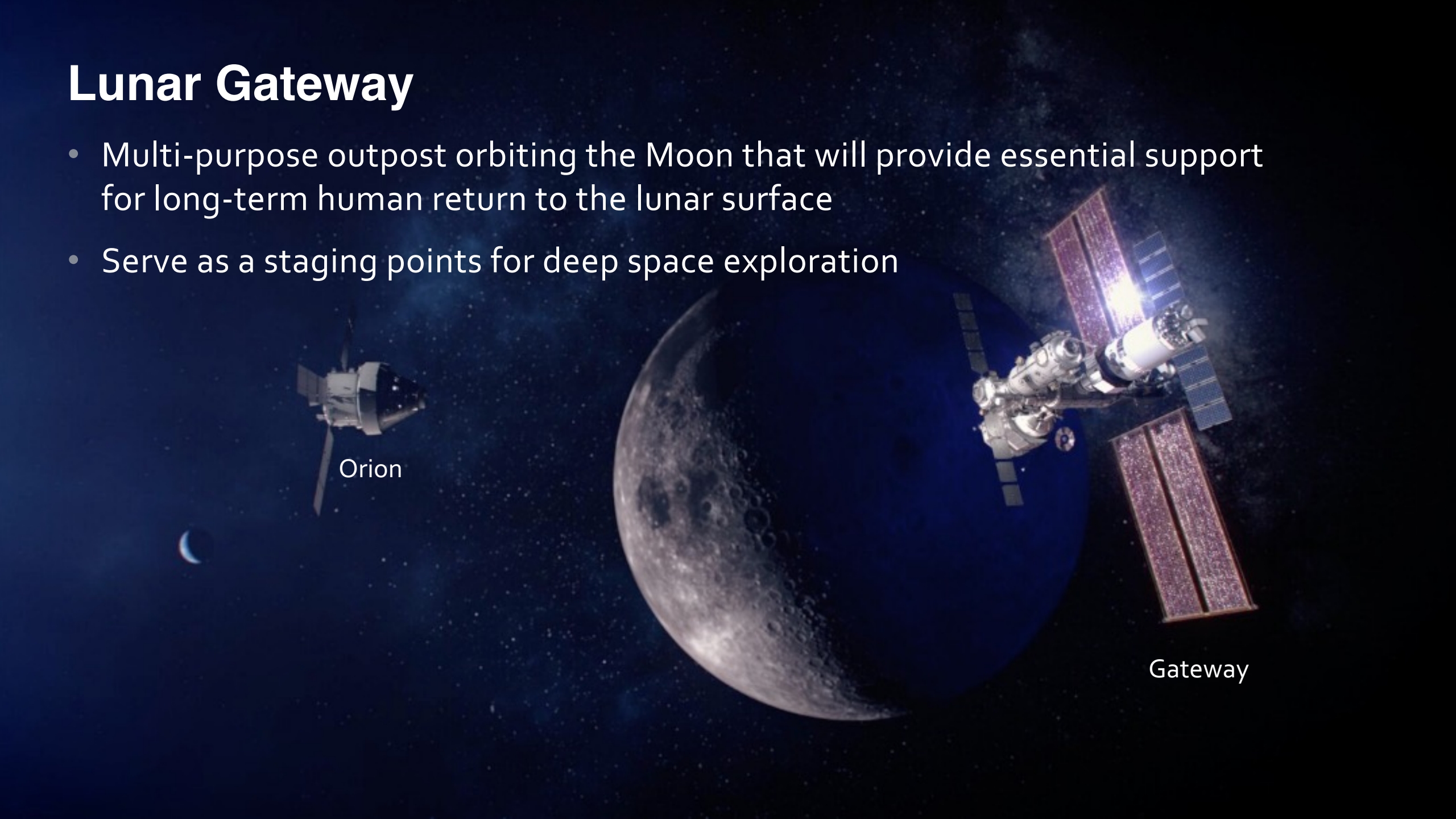
SLS RT-455 inspection:

- Surface effects (dents, pits, bumps, scratches) leading to signal anomalies
- After significant data analysis and data collection, no conclusive evidence of any large voids

POC: Eric Burke and Eric Madaras

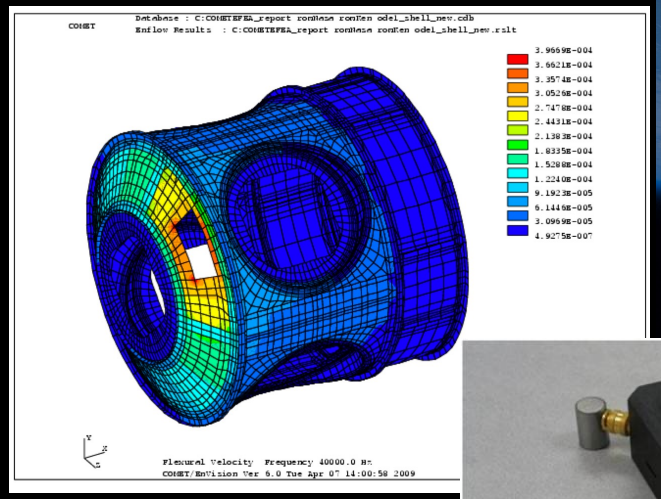
Lunar Gateway

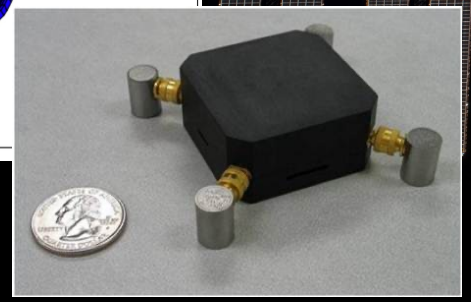
- Multi-purpose outpost orbiting the Moon that will provide essential support for long-term human return to the lunar surface
- Serve as a staging points for deep space exploration

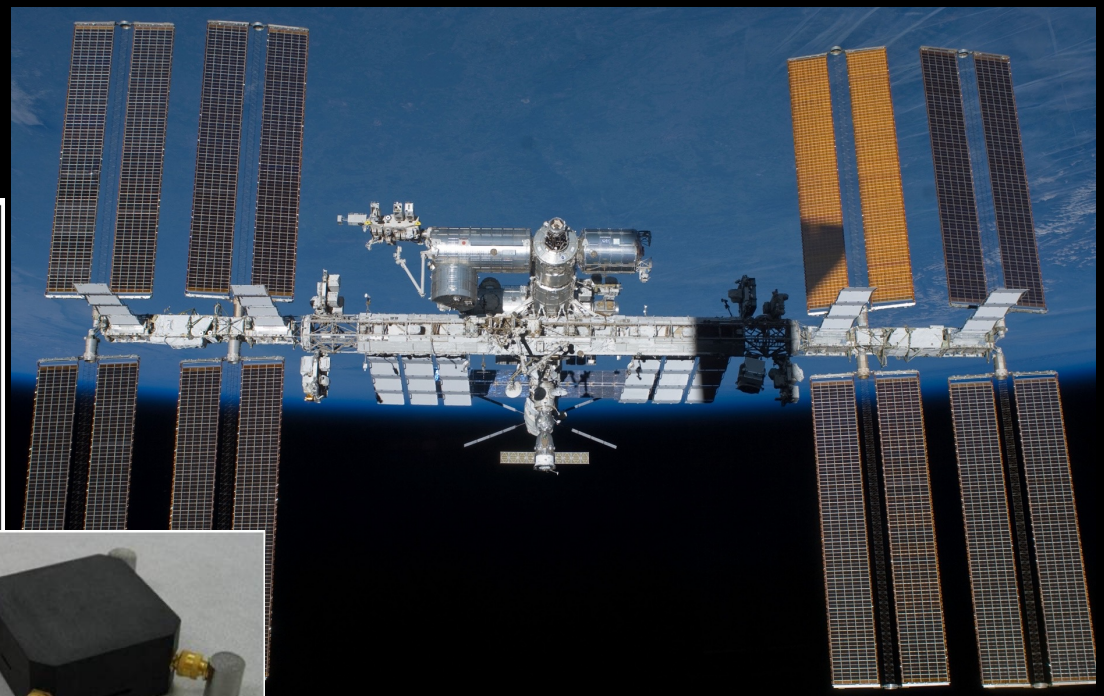


Gateway

- Potential future opportunity to test health monitoring (in-situ NDE) sensor systems







Ultrasonic Leak Location System tested on International Space Station

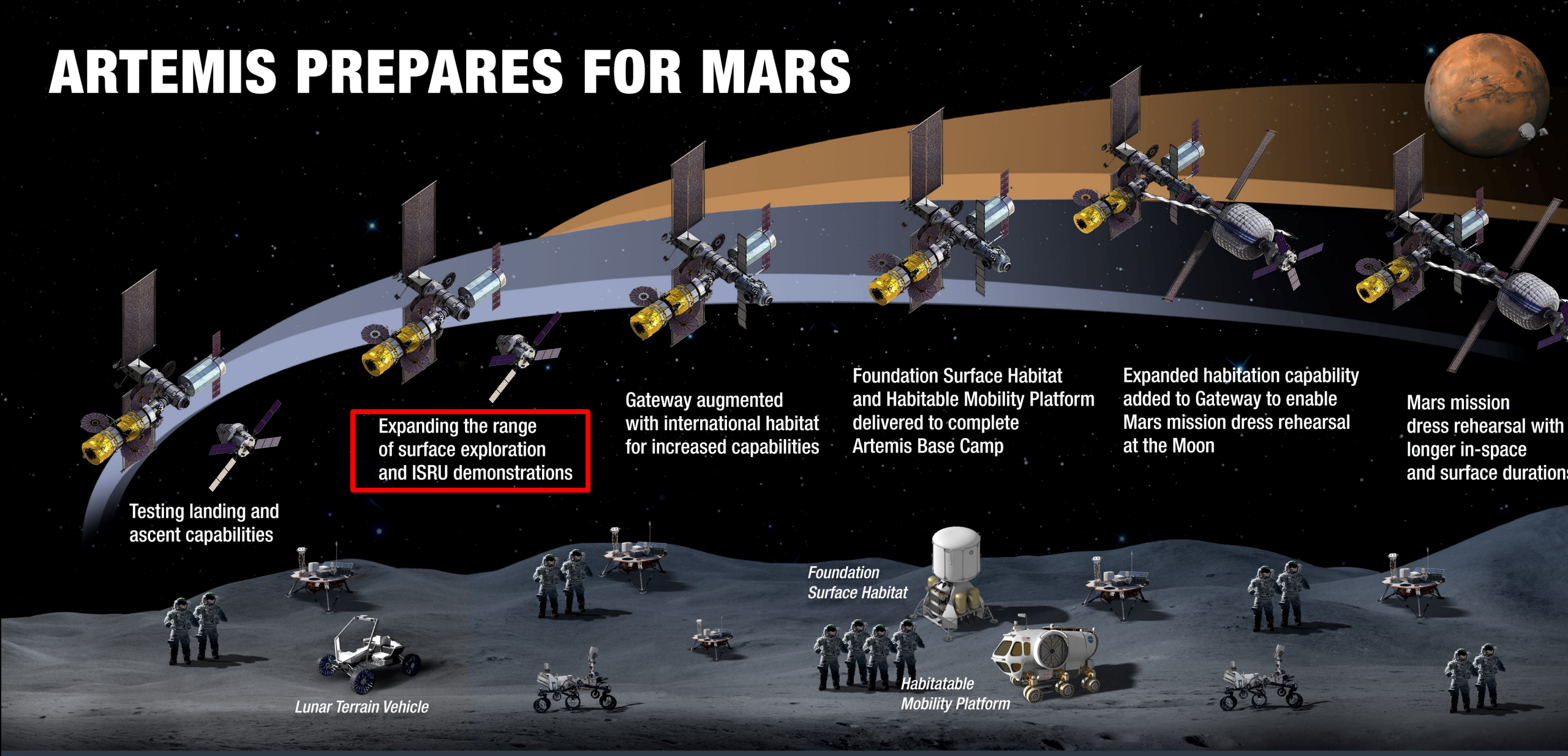
Once we get there:

- Crewed moon and mars missions will require infrastructure such as habitats to enable surface activities – especially for longer missions



Illustration, Lunar South Pole Artemis Base Camp

ARTEMIS PREPARES FOR MARS



SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

MULTIPLE SCIENCE AND CARGO PAYLOADS | INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

Moon to Mars Planetary Autonomous Construction Technologies (MMPACT)

- Goal: On-demand capabilities to protect astronauts and build infrastructure on the lunar surface with in-situ resource utilization to create launch/landing pads, habitats, shelters, roadways, etc.
- Raw lunar regolith with binder materials (such as calcium, sulfur, aluminum, magnesium, and others) to create extruded materials
- Directed energy methods, such as microwave sintering, laser sintering, and high temperature methods for melting and sintering regolith[1]

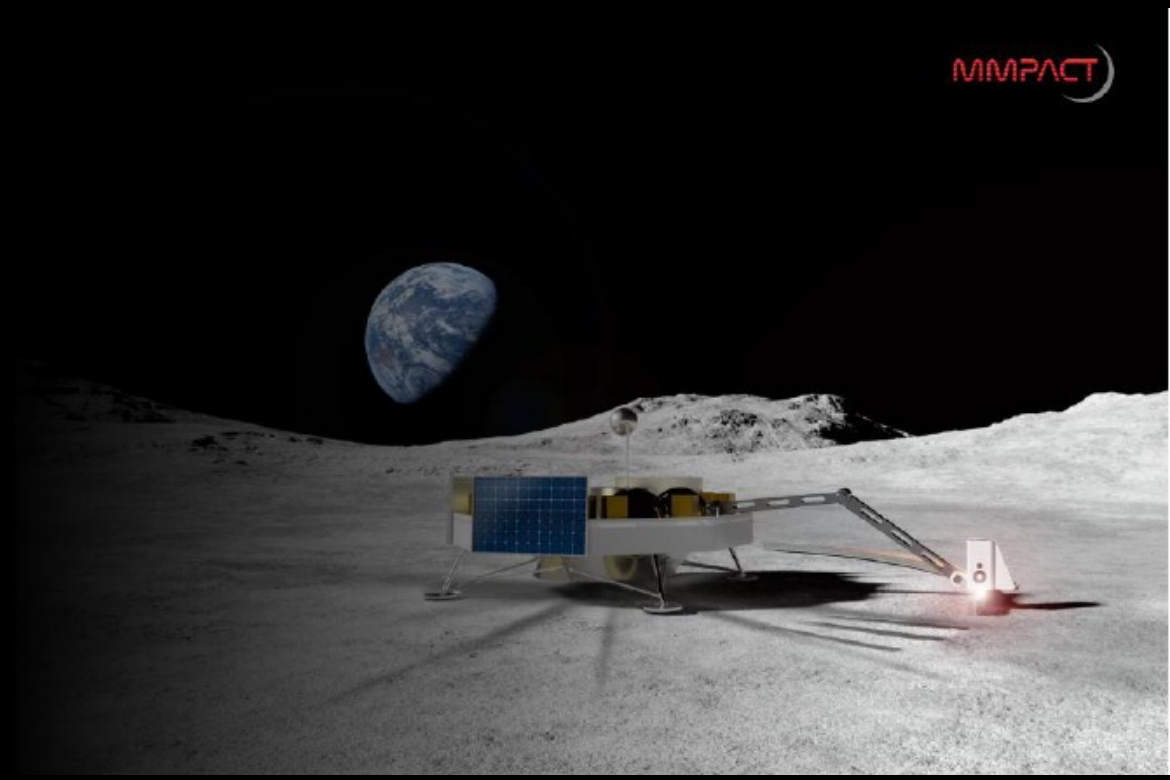


More details: Clinton, Raymond G., et al. "Overview of NASA's Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT)." *ASCEND 2021*. 2021. 4072.

In-Situ Manufacturing with Lunar Regolith: NDE

- NDE can aid initial materials down select
  - Extruded materials – mixing binders with lunar regolith ('lunar concrete' type approach)
  - Sintered materials – applying high heat to lunar regolith

- NDE on the moon:
  - Autonomous inspections
    - Monitoring during manufacturing
    - Inspection post-manufacture

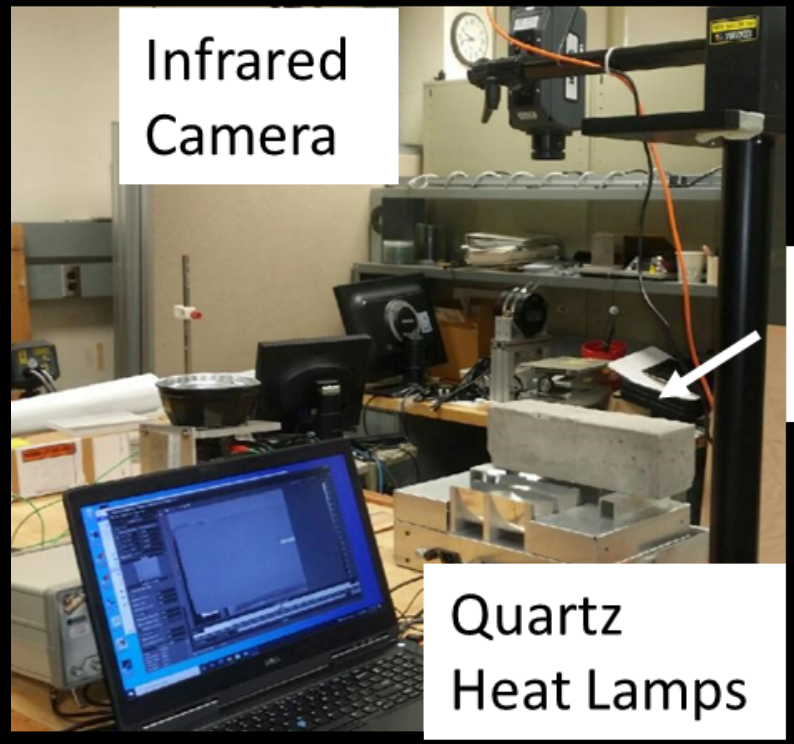


MMPACT: Ongoing Activities

Material Inspectability Assessment

Through-transmission Thermography for MMPACT regolith beam sample:

- Midwave IR camera opposite the heat source
  - The frame rate was 15 Hz and 92,051 frames were acquired.
- Quartz lamp heat source directed onto sample
- Temperature rise on back surface ~165 C
- Camera captured the front surface temperature.
- The inspection image was produced using a curve fit to a 1-dimensional thermal model.



POC: Joseph Zalameda

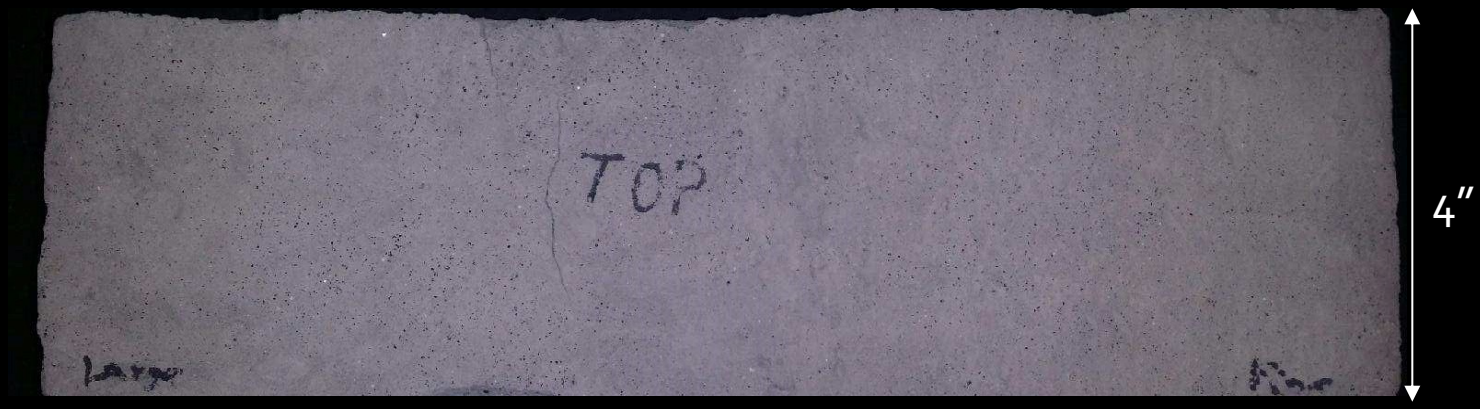
Material Inspectability Assessment

Results

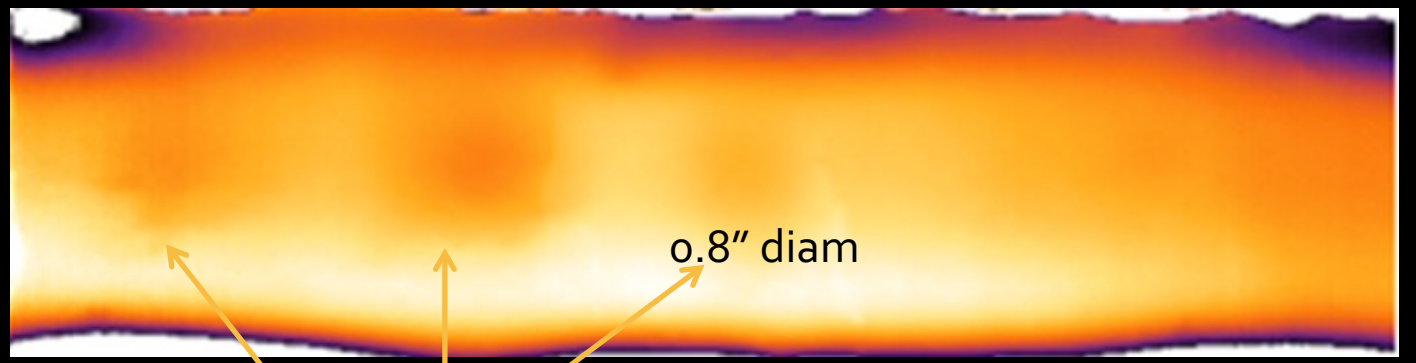
- Inspection shows three largest void defects
- Good surface emissivity and thinner samples or near surface voids = good candidate for thermal inspections during manufacturing
- Single sided thermal inspection data processing ongoing
- Additional samples expected

POC: Joseph Zalameda

Top of Sample



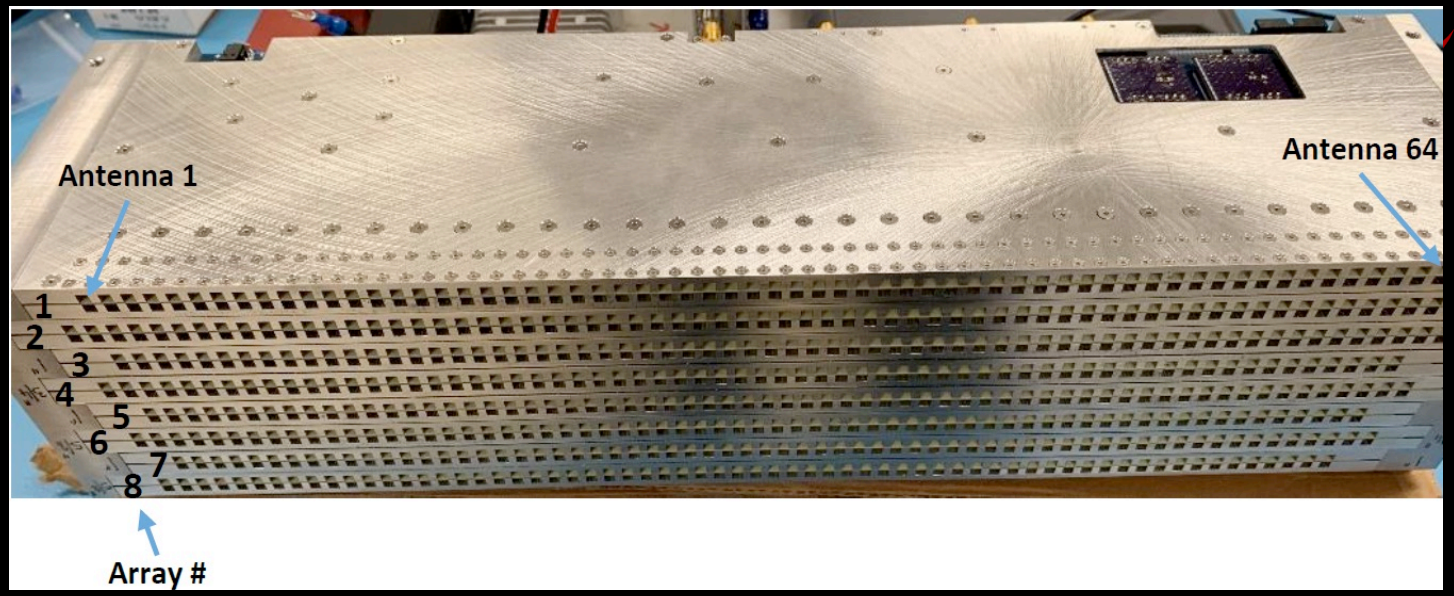
Thermal Diffusivity Inspection Image



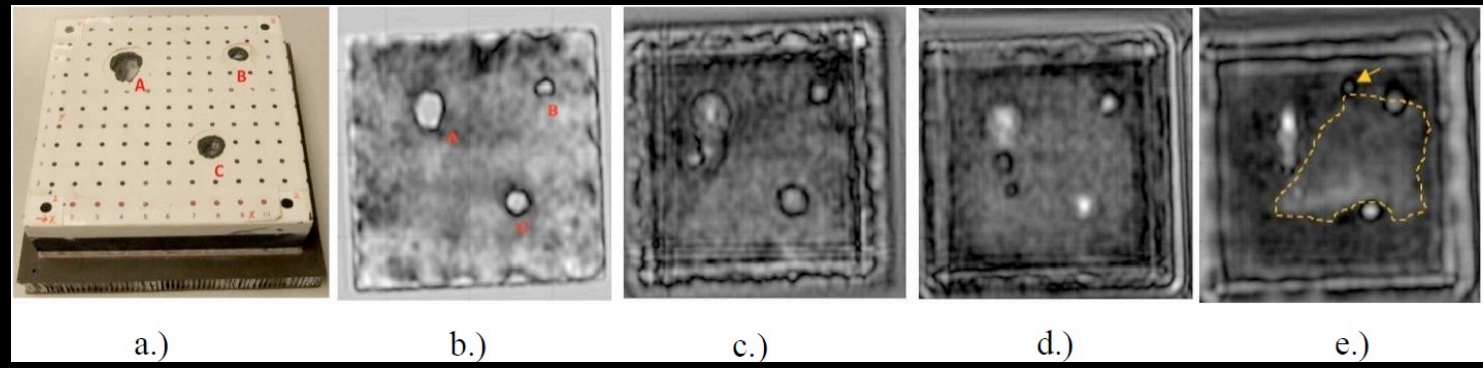
Millimeter Wave Imaging

- NASA SBIR Phase 2: Texas Research Institute and Iowa State University
- Millimeter wave synthetic aperture radar (SAR) imaging system.
- High-resolution 3D images
- 8 linear arrays, each containing 32 transmitting and 32 receiving antennas (512 total) and performs multi-static measurements.
- Operation frequency range of 24–40 GHz.
- Cross-range resolution (lateral directions) of ~2.5 mm and along-range resolution of ~9.4 mm (depth direction) in air (increases in dielectric)
- Imaged a high-temperature reusable surface insulation (HRSI) tile sample with *simulated* micrometeoroid and orbital debris strike damage.
- Using the SAR algorithm, 2D image slices from the 3D data, at several relevant depths were generated.
- Under investigation for MMPACT project

NASA POC: Cy Wilson, ISU POC: Doyle Motes



TRI and ISU's multi-static imaging array developed in the Phase II SBIR effort consisting of 8 linear arrays, each with 64 antennas.



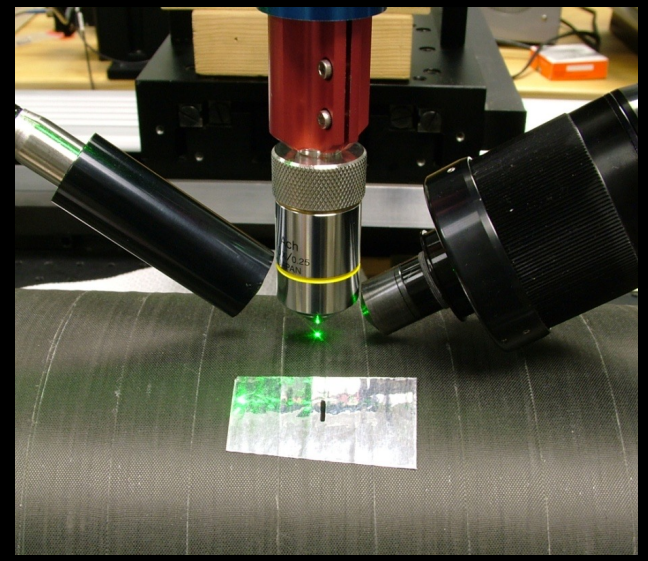
(a) HRSI tile attached to a honeycomb composite panel with simulated MMOD damage and 2D slices of the Ka-band (26.5-40 GHz) 3D SAR image at several depth levels; (b) surface of tile, (c) 20 mm deep, (d) 30 mm deep, and (e) bottom surface of the tile.

Characterization of Lunar Regolith

- Properties of the lunar regolith affect the resulting construction material
- Knowledge of properties as-measured on-surface could guide changes to manufacturing process (e.g., selected heating)
- Lunar regolith simulant testing guides on-surface analysis options

- Raman Spectroscopy
  - vibrational modes of a molecule excited by inelastic light scattering
  - allows chemical identification for the sample

- In-use by NASA to aid other off-planet chemical identification applications, such as Mars Perseverance Rover



Raman measurements on a composite sample

POC: Eric Tucker

Benchtop Raman Data for Lunar Simulant Samples

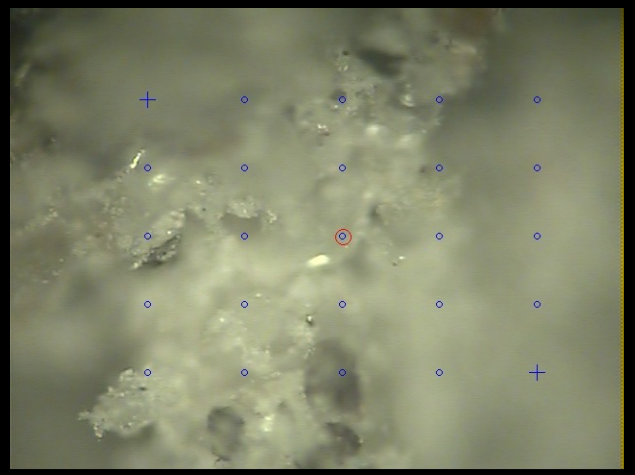
Goal: Determine whether Raman spectroscopy can identify main minerals in lunar regolith

System: Benchtop commercial system, 200mW laser power used

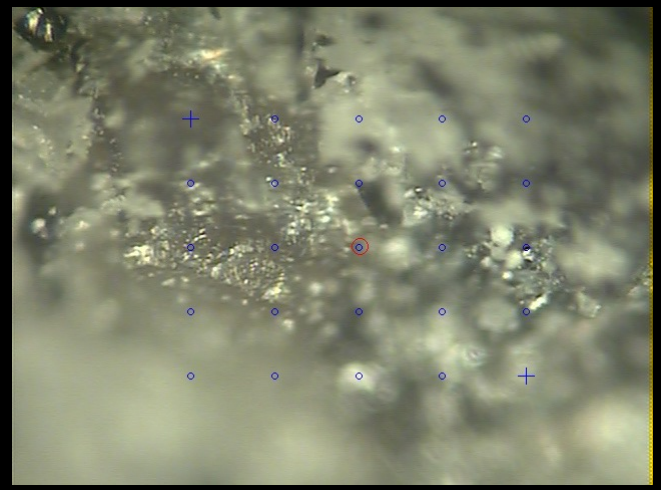
Measurement details:

- Measured two different lunar regolith simulant samples: Lu-LHT-4M and OB1A
- Collected 5x5 points across a small area of sample underneath microscope

LU-LHT-4M sample, optical image



OB1A sample, optical image



POC: Eric Tucker

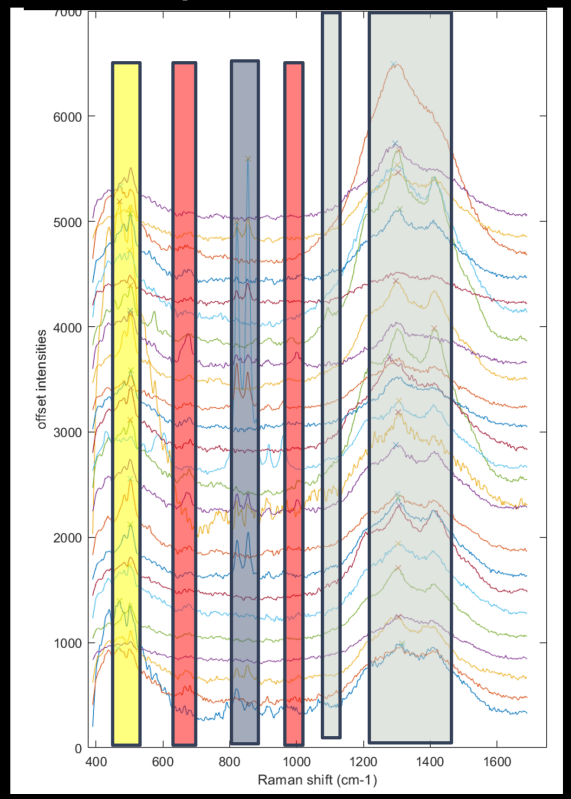
Lunar Simulant Samples

- Clear peaks observed in some measurements
- Some peaks obscured due to background
- Benchtop system generally able to identify some primary constituents in raw lunar simulant *and* lunar simulant-based construction material (not shown here)

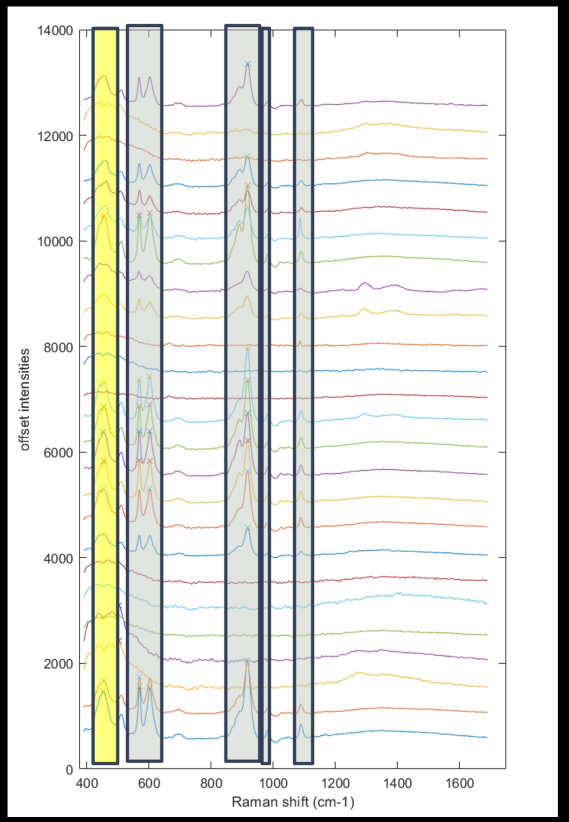
Next steps:

- Repeat the above testing with portable Raman instrument in development at LaRC

LU-LHT (lunar highlands type) **-4M sample**



OB1A (olivine-bytownite) **sample**

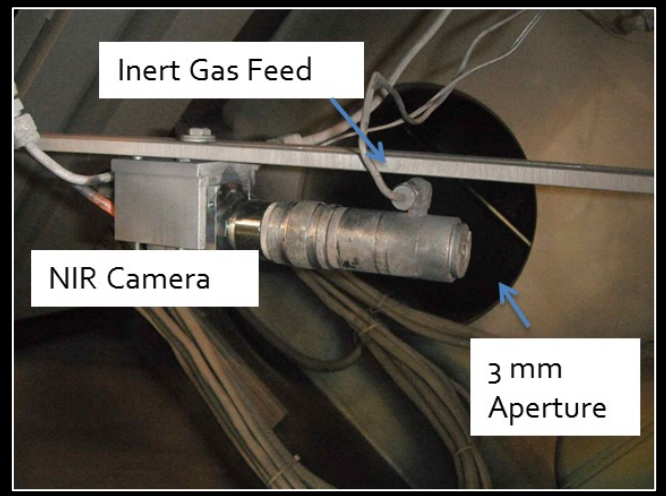


Plagioclase (light yellow shaded region), Olivines (light blue shaded region), Pyroxenes (light red shaded region), and Unidentified species (light green shaded region)

POC: Eric Tucker

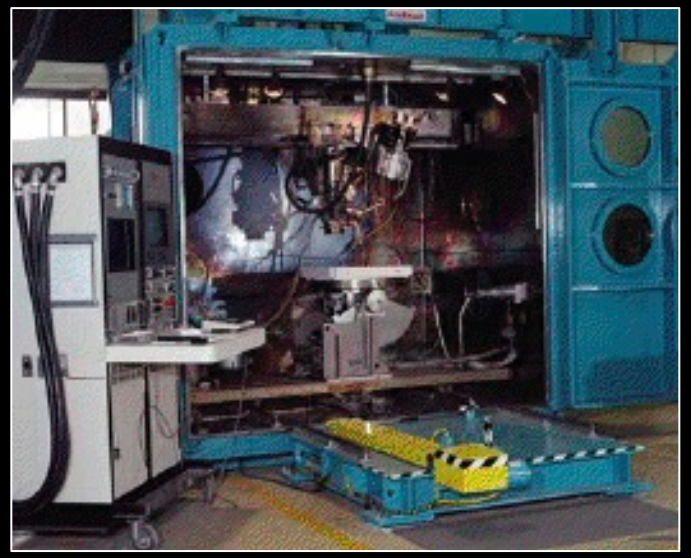
In-Space Manufacturing

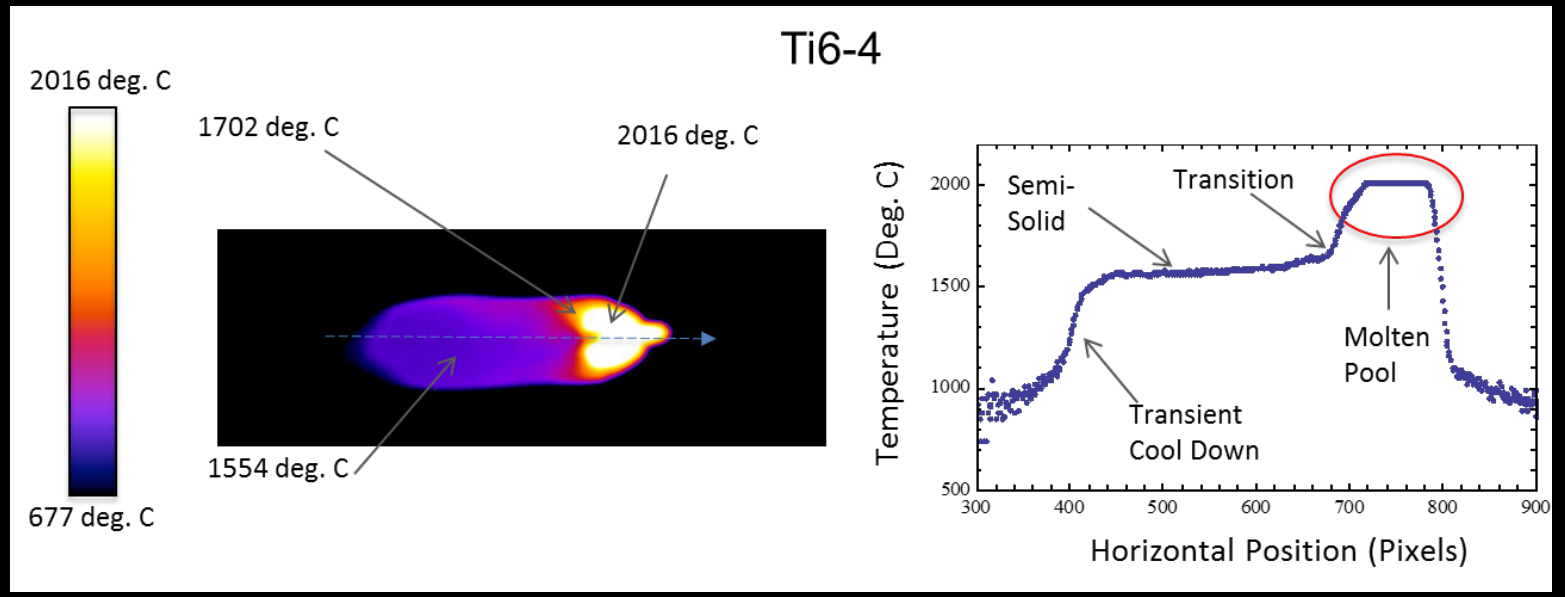




- On-demand wire-feed additive manufacturing with dissimilar alloys
- Potential for for on-orbit applications
- Thermal monitoring for direct feedback loop to guide the manufacturing process

Electron Beam Free Form Fabrication

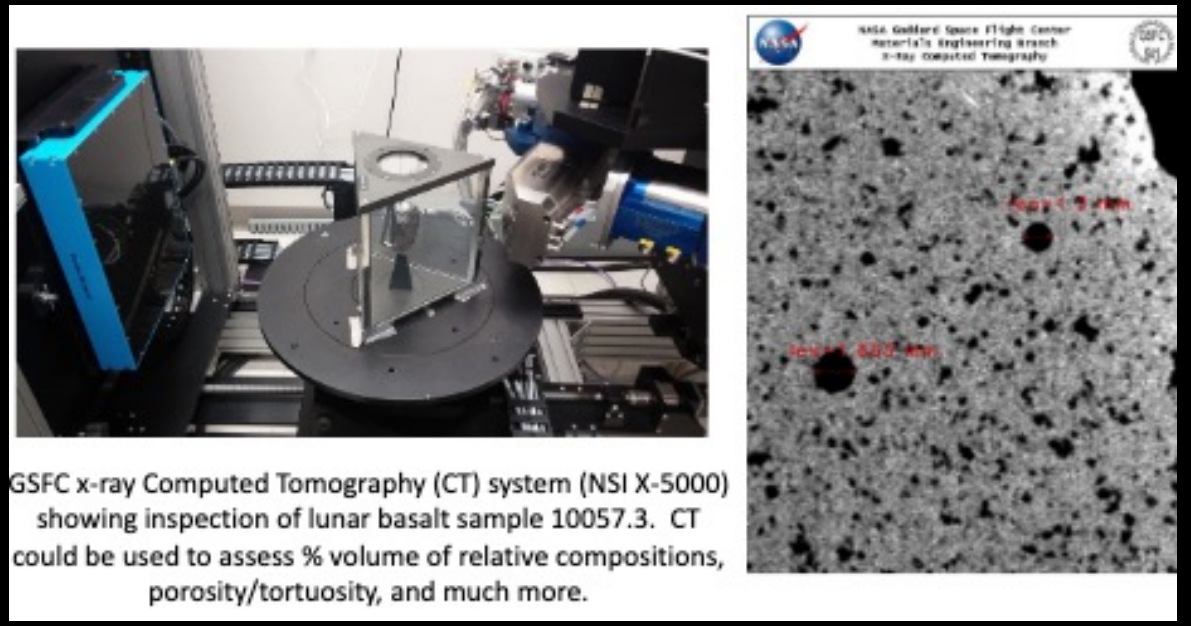




POC: Eric Burke, Joseph Zalameda

In-space Manufacturing

- Currently heavy reliance on X-ray Computed Tomography (CT) for inspection of additive manufactured components for spaceflight
- NASA Goddard is leading investigation of X-ray CT for in-space environment
  - Non-funded partnership with North Star Imaging
- Concept development and trade studies on CT in different environments (including on-orbit, lunar, and Martian)



GSFC x-ray Computed Tomography (CT) system (NSI X-5000) showing inspection of lunar basalt sample 10057.3. CT could be used to assess % volume of relative compositions, porosity/tortuosity, and much more.

POC: Justin Jones, GSFC

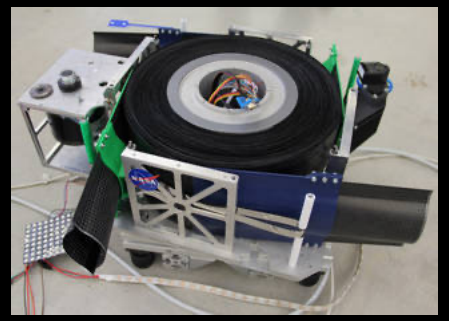
https://ntrs.nasa.gov/citations/20210019431

Uncrewed Space Exploration: Solar Sail

- Solar sails employ the pressure of sunlight for propulsion, eliminating the need for conventional propellant.
- Deployable composite booms are 75% lighter and experience less in-space thermal distortion compared to thin-shell metallic booms.





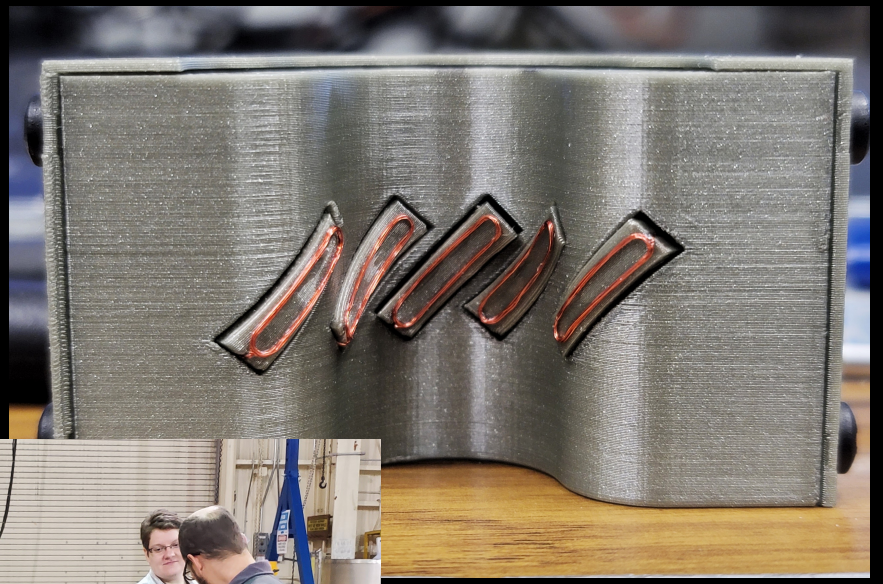




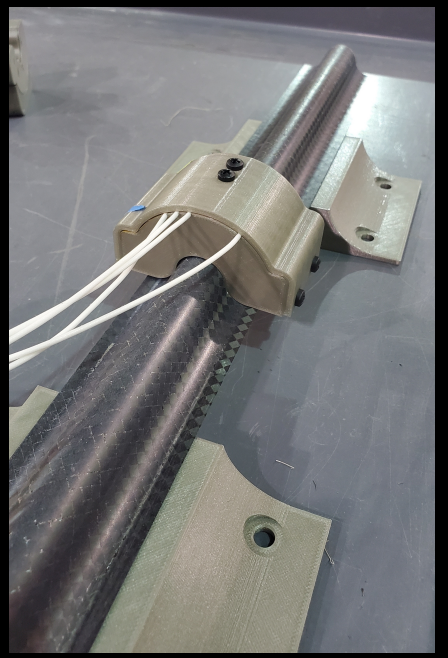
NASA's ACS3 solar sail, 900 square feet (80 square meters), uses 23-foot (7-meter) booms.

Composite Boom Inspection

- 7 meter composite booms
- Custom eddy current probes created with 3 coil and 4 coil conformal designs to scan flange and transition regions
- 100% of visible cracks were detected
- Some regions without visible cracking also flagged as regions of interest
  - Will continue to monitor during roll-up tests



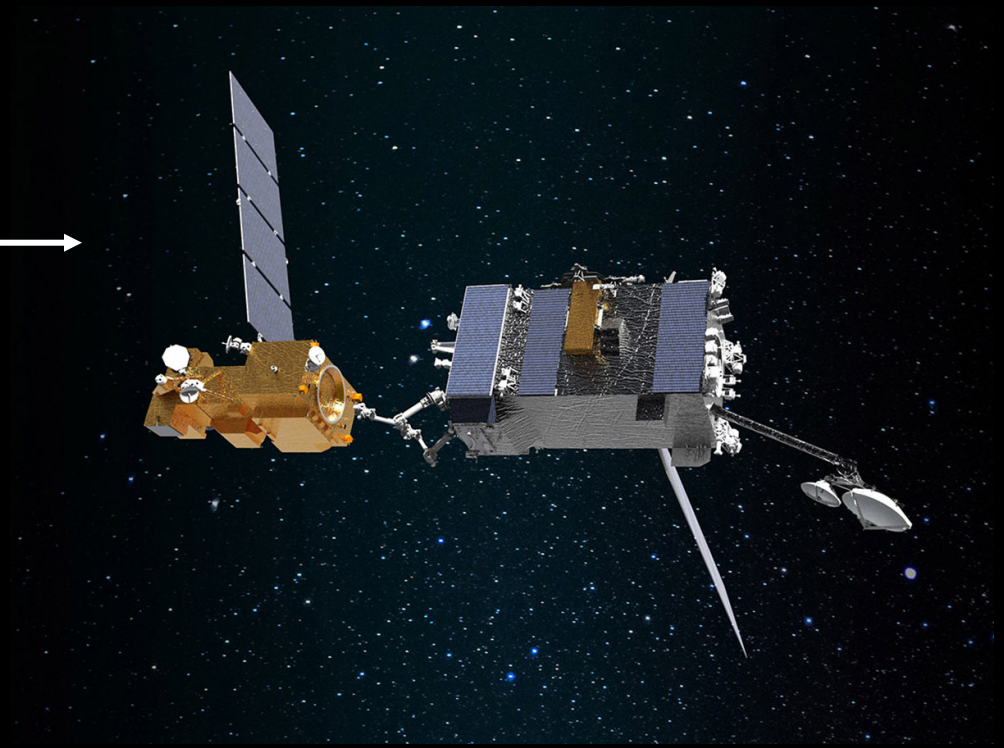




Robotic Space Activities

- **On-orbit Servicing, Assembly, and Manufacturing (OSAM)**
  - Servicing – repair, replace, refuel – could include inspection
  - Assembly – launch individual components and robotically assemble in space
  - Manufacturing – fabrication of components in space as needed

Illustration for OSAM-1 (short for On-orbit Servicing, Assembly, and Manufacturing 1) concept, a robotic spacecraft equipped with the tools, technologies and techniques needed to extend satellites' lifespans
Demonstration: 2025+ timeframe



Mars Sample Return (MSR)



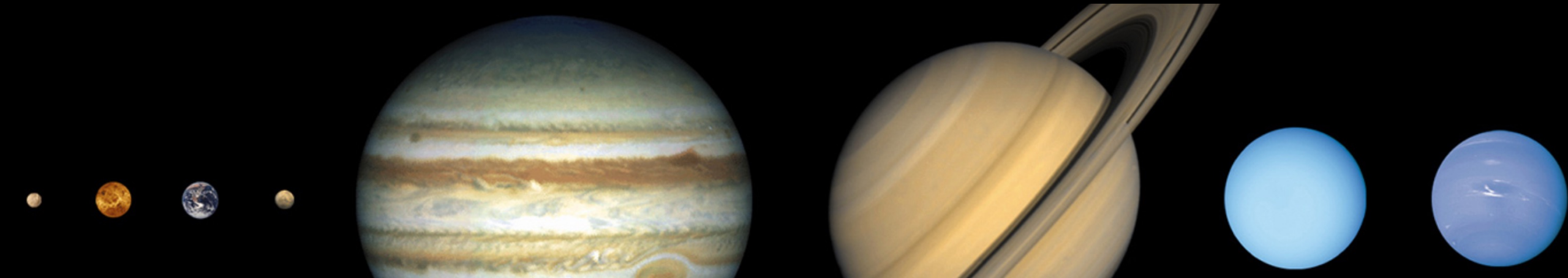
MSR: NDE

- Inspections help assess the quality of the path finder articles for the MSR Earth Entry Vehicle (MSR-EEV) to confirm and optimize MSR structural configurations.
  - Quality of the composite structure assessed via:
    - Flash thermography, x-ray computed tomography (CT), Ultrasound (UT) and Creaform coordinate measurement system.



Thermal inspection of Aeroshell

We have a goal to create a blueprint for sustained human presence and exploration throughout the solar system...
~Pam Melroy, NASA Deputy Administrator



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Useful resources:

1. https://ntrs.nasa.gov/citations/20210019431 – by Justin Jones GSFC
2. Clinton, Raymond G., et al. "Overview of NASA's Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT)." *ASCEND 2021*. 2021. 4072.
3. https://www.nasa.gov/specials/artemis/